WHITE PAPER NO. 3 – FOX RIVER BATHYMETRIC SURVEY ANALYSIS

Response to a Document by Limno-Tech, Inc.

REVIEW OF USEPA FIELDS ANALYSIS OF BED ELEVATION CHANGES IN THE LOWER FOX RIVER

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This Document has been Prepared by

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ABSTRACT

This White Paper has been prepared in response to the Fox River Group's *Review of USEPA Fields Analysis of Bed Elevation Changes in the Lower Fox River* (LTI, 2001). The LTI Report suggested that the models used in the *Remedial Investigation for the Lower Fox River and Green Bay, Wisconsin* and *Feasibility Study for the Lower Fox River and Green Bay, Wisconsin* incorrectly uses the historic bathymetric data in the analysis of sediment bed dynamics. In response to that LTI report and the comments received, the FIELDS Team created a visual product based on the historic bathymetric surveys of the Lower Fox River to show changes in sediment elevation and volume between survey years. The results of the analysis showed sediment movement within and outside of the dredge areas.

Fox River Bathymetric Survey Analysis

Prepared by the FIELDS Team, U.S. EPA, Region 5, Superfund Division

Introduction

The FIELDS Team was asked by the USEPA Fox River Remedial Project Manager to create a visual product of the U.S. Army Corps of Engineers' (COE) historic bathymetric surveys of the Lower Fox. The COE survey data encompassed the years 1995 through 2000 and were collected to support the COE's navigation dredging activities. The FIELDS Team interpolated (created estimates of) the COE bathymetric data and displayed these estimates on maps to show the changes in sediment elevation and sediment volume between survey years. The results demonstrate that sediment movement does occur, both within and outside of dredge areas. This document explains the methods, results, and conclusions found by the FIELDS Team. It replaces any previous USEPA maps and analyses of the Fox River bathymetric data. This report is intended to explain the methods of analysis on previous, as well as current, bathymetric survey data. Additionally, the report addresses specific questions from Limno-Tech, Inc about previous analyses. This analysis of the data pays particular attention to the method of estimation at unsampled locations, survey accuracy (+/-), and survey timing (whether the survey is pre- or post-dredge). Addressing these issues will help explain the limitations of the data and reduce uncertainty in the conclusions.

Methods

<u>Data sources</u>
The data used for this document include the following:

1. Bathymetric Data: CD - "Lower Fox River USACE Hydrographic Survey Data 1995 - 2000", dated April 19, 2002. Limno-Tech, Inc.

2. Dredge Dates: USACE Dredging Report, Detroit District Website
<u>http://huron.lre.usace.army.mil/OandM/o&m.html</u>

3. Bathymetric Survey Dates: Mike Stencil, U.S. Army Corps of Engineers, Kewaunee Area Office (Personal Communication)

The FIELDS Team received the bathymetric survey transect data as a text file (*.xyz) from the COE via Limno-Tech, Inc. The 10 data files covered the years 1995 to 2000. In 1995 and 1996, the survey data included only the area from the Fort Howard Turning Basin (FHTB) through the mouth of the Lower Fox River. For the years 1997-2000, the survey data extend farther upstream than the FHTB, up to the DePere Dam. Using Microsoft Excel, the files were combined so that each year was a separate, complete file. The data were reprojected from UTM Zone 16 to Wisconsin Transverse Mercator, NAD 27, using FME and converted to shapefiles in ArcView, a GIS software (see Figure 1).

The dredge dates are provided in Table 1. The bathymetric survey dates, locations, and whether or not the survey occurred after a dredge event are provided in Table 2.

COE Bathymetric Survey Accuracy

The COE states that the accuracy of their bathymetric surveys is ± 0.5 feet based on the use of a bar check before and after each bathymetric survey (Mike Stencil, Personal Communication). Bathymetric surveys conducted by the FIELDS Team also have found an accuracy better than ± 0.5 feet measured by comparing resamples of the same area. The authors of the LTI Review note that survey elevation changes within ± 1.4 feet are "within the range of uncertainty inherent in the survey equipment, survey methods, and data analysis techniques" (LTI Review, p. 1). Using ± 1.4 ft as an analytical control is overly conservative but was used, in this document, to compare the results obtained from assuming an accuracy of ± 0.5 feet with ± 1.4 feet (see Figure 2).

Interpolation

The purpose of interpolation is to create estimates at unsampled locations. The usefulness of interpolation is the ability to view point data (e.g., bathymetric survey data) as gridded (estimated) values that represent a surface. More significantly, interpolation allows one to estimate linear differences (e.g., 1996 sediment elevation estimates – 1995 sediment elevation estimates), area differences (e.g., proportion of surface area changes for a specific range), and volume differences (e.g., cubic yards of sediment lost or gained over time). The interpolation algorithms Inverse Distance Weighting (IDW) and Natural Neighbor were used to create estimates of sediment elevation at unsurveyed locations. These interpolation algorithms, like all other interpolation algorithms, "behave" better or worse, as regards to the original data, depending on the density and spacing of the original data, edge effects, and data clustering.

The COE bathymetric survey data were converted to shapefiles and were interpolated using the Inverse Distance Weighting (IDW) algorithm in ArcView's Spatial Analyst extension. The parameters used in the IDW algorithm were a power of 2, neighbor of 8, and a cell size of 5 meters (see Figure 3). These parameters were found to have the lowest cross validation residual (root-mean square error) using the FIELDS Tools (www.epa.gov/region5fields/). The lowest root-mean square error refers to the difference between interpolated values and the original values. Hence, interpolation parameters that give the lowest root-mean square error are often preferred. The data were not interpolated outside the lateral boundaries of the survey extent by the use of a polygon of the Fox River navigation boundary. The interpolated data were used to find differences in sediment elevation, sediment volume, and sediment surface area by various year combinations (e.g., 1996 – 1995) using ArcView's Map Calculator function. These differences were displayed in maps with dredged areas of Fox River designated by color-coded polygons (see Figure 4).

In order to assess potential bias in the interpolations, the bathymetric survey data for some of the years were interpolated using different powers and neighbors in the IDW algorithm. In addition, a different interpolator, Natural Neighbor, was also used to create estimates of sediment elevation. The results were used to compare the effects that different parameters and a different interpolation algorithm had on the results. The new results were compared year to year (see Figure 5). The new interpolations were also compared to the original interpolation (IDW, power of 2, neighbor of 8) and the difference between the two grids was calculated and displayed in a map format (see Figure 6).

<u>Outstanding Issues</u>
After acquiring the bathymetric survey dates from the COE Kewaunee office it became evident that some dredged areas were surveyed after the dredging event occurred. These areas were marked with asterisks on the maps (see Figure 7). Efforts are currently being made to determine if the data we used were, in fact, post-dredge, and how often this occurred in the data set (i.e., a more accurate Table 2).

Results and Discussion

<u>Comparisons of Interpolation Algorithms</u>
Several comparisons of interpolation (estimation) algorithms and parameters were performed in order to evaluate their significance. These results are presented, by section, below.

1. Changes caused by Inverse Distance Weighting (IDW) parameters

    There appears to be little difference in the interpolated sediment elevation values for the maps of 1995-1996 and 1996-1997 when the IDW parameters are changed from a Power of 2, Neighbor of 8 to a Power of 6, Neighbor of 4 (see Figures 8a-d). This visual evaluation is confirmed from Figures 9a-d that show the numeric difference in interpolated sediment elevation values. These figures demonstrate that those areas with differences in interpolated sediment elevation occur along the edges of the study area for both accuracy values (± 0.5 and ± 1.4 feet). This is expected as any interpolator performs less well at the spatial extent of the original data due to a lack of data values.

    There appears to be little difference in the interpolated sediment elevation values for the maps of 1995-1996 and 1996-1997 when the IDW parameters are changed from a Power of 2, Neighbor of 8 to a Power of 6, Neighbor of 12 (see Figures 10a-d). This visual evaluation is confirmed from Figures 11a-d that show the numeric difference in interpolated sediment elevation values. These figures demonstrate that those areas with differences in interpolated sediment elevation occur along the edges of the study area for both accuracy values (± 0.5 and ± 1.4 feet). This is expected as any interpolator performs less well at the spatial extent of the original data due to a lack of data values.

2. Changes caused by Interpolator

    Unlike the limited difference in the effect of differing IDW parameters, there are some differences in a visual evaluation of the interpolated sediment elevation values for the maps of 1995-1996 and 1996-1997 when IDW is compared to Natural Neighbor (NN).

(See Figures 12a-d.) However, as noted above, most of these differences occur at the edges of the study area. This finding is confirmed by Figures 13a-f. (These figures show the difference in interpolated sediment elevation values at two different accuracy values, ± 0.5 and ± 1.4 feet.)

Interpolated sediment elevation values (IDW, power of 2, neighbor of 8)

There were several sets of maps created from the interpolations of the bathymetric survey data. These results are presented, by section, below.

1. Comparisons of Accuracies (by year, including dredged and non-dredged areas)

   The "side-by-side" (see Figures 14a-f) maps show the differences in interpolated sediment elevation values using different accuracies by year. As demonstrated, quantitatively, in the "Volume estimates" section below, the use of an accuracy value of ± 0.5 feet (Figures 15a-f and 17a-f) versus ± 1.4 feet (Figures 16a-f and 18a-f) makes a very large difference. The maps show that there is a large decrease in areas considered to have significant change in sediment elevation when an accuracy value of ± 1.4 feet is used. All maps show that the changes in sediment elevation are spatially dispersed.

2. Comparisons (by year and accuracy, including dredged and non-dredged areas)

   Figures 15a-f and 16a-f provide a visualization of differences in interpolated sediment elevation values on a year-to-year basis for the entire study area. Many of the areas that show the largest decreases in interpolated sediment elevation values are in dredged areas. A year-to-year description is provided below:

   1995-1996: There were three areas dredged between the Fort Howard Turning Basin and the mouth of the river (see Figures 15a and 16a). Based on information received from the COE Kewaunee office, these areas are suspected to have been surveyed after the dredging occurred. This idea is supported by a visual inspection of the map itself. Transects 0+00 to 10+00 and 19+00 to 30+00 show negative change, while there is positive change in the Fort Howard Turning Basin. There is another section of the river (142+00 to 177+00) that also shows a positive change in sediment elevation. This area was not dredged in 1995 or 1996, but was dredged in 1994. There are also smaller areas of change, both positive and negative at the East River junction.

   Using an accuracy estimate of ± 0.5 feet shows that there is more change overall, and the above noted changes stand out a little less, because they are surrounded by areas of smaller positive or negative change in sediment elevation (see Figure 15a). For instance, at the East River junction, the area of negative change is much bigger. There is also positive change evident between 123+00 and 136+00 that was not shown on the previous map because it falls in the range of ± 0.5 feet. In addition, there are areas of positive change in the Fort Howard Turning Basin along the east bank of the river.

   1996-1997: In this map again there is a section of the river that was supposedly surveyed after it was dredged, and shows negative change (see Figures 15b and 16b). This is in the area north of the Fort Howard Turning Basin, transects 142+00 to 172+00. Another significant area of negative change is in the Fort Howard Turning Basin itself, the area dredged in 1996. Where there was positive change at this location in the 1995-1996 comparison, the comparison of 1996-1997 shows a negative change. There is also a small area of negative change between 85+00 and 97+00 that is consistent with a dredge event, but there is no USACE record of a dredge event in that specific area.

Using an accuracy estimate of ± 0.5 feet shows that the Fort Howard Turning Basin has a negative change on the east bank and positive change on the west bank (see Figure 15b). Using this uncertainty estimate shows more areas of change in the range of ± 0.5 feet, scattered about the river.

1997-1998: As in previous maps, the Fort Howard Turning Basin was suveyed in 1998 after dredging occurred (see Figures 15c and 16c). However, in this case, the change in sediment elevation is not as clear. The change is not as focused or consistent, but there is some obvious negative change. Also between 142+00 and 172+00 there is evidence of a positive change. This area was dredged in 1997.

Using an accuracy estimate of ± 0.5 feet shows that there is a much higher percentage of positive change in the ± 0.5 feet range, specifically from 0+00 to 33+00 and 142+00 to 177+00, with scattered change in between (see Figure 15c). The Fort Howard Turning Basin shows more negative change in the range of -1.5 to -0.5 feet.

1998-1999: Unlike previous comparisons, in this case there appears to be no areas that were dredged prior to the survey (see Figures 15d and 16d). This comparison also shows less change. There is a positive change in the Fort Howard Turning Basin, which was dredged in 1996 and 1998, and also positive change north of the turning basin, between 142+00 and 172+00. This area was dredged in 1997. There is also some smaller areas of positive and negative change at the East River junction.

Using an accuracy estimate of ± 0.5 feet shows that there is more positive change evident in the range of 0.5 to 1.5 feet especially in the Fort Howard Turning Basin, and near the mouth of the river (see Figure 15d). There is scattered areas of negative change in the range of -1.5 to -0.5 feet from the mouth of the river to 142+00, especially at the East River Junction.

1999-2000: In this comparison again, the area between 142+00 and 177+00 was dredged prior to the survey (see Figures 15e and 16e). While there is obvious change here, it is both positive and negative all in the same area. There are also small areas of negative change at the East River junction, and moderate areas of positive change in the Fort Howard Turning Basin. In addition, there is some smaller spots of positive change near the mouth of the river.

Using an accuracy estimate of ± 0.5 feet shows more positive change of 0.5 to 1.5 ft near the mouth of the river, in the turning basin, and between 123+00 and the turning basin (see Figure 15e). There is also some scattered negative change at the East River junction and throughout the river.

1995-2000: Figures 15f and 16f show the changes in interpolated sediment elevation values from 1995 through 2000. Both within and outside of dredge areas, there is significant changes in interpolated sediment elevation values. The majority of the dredge areas show declines in interpolated sediment elevation values, while those areas outside of historic dredge areas show increases.

3. Comparisons (by year and accuracy, in non-dredged areas only)
   These maps, Figures 17a-f and 18a-f, show the changes in elevation on a year-to-year basis using accuracy values of ± 0.5 feet and ± 1.4 feet, respectively. The maps demonstrate a consistent change (both increases and decreases) in sediment elevation across from the former Fort James plant (now Georgia Pacific) over time. (See the "elbow" on the right-hand side of the maps.) This is likely due to ship traffic in the area. Most significantly, the comparison of 1995 to 2000 shows the cumulative changes in sediment elevation over this five-year period (see Figures 17f and 18f). The majority of areas showing changes in interpolated sediment elevation are positive values.

Volume estimates

Table 3 displays the estimates of sediment volume changes in cubic yards (cu. yd) by one-year increments, save for the last entry in the table which shows the change between 1995 and 2000, for areas that were not dredged. The values in the two columns with the header "± 0.5 ft" and "± 1.4 ft" provide estimates of the gain and loss of sediment volumes by year. The difference between these two columns is the accuracy value used. The first column uses an accuracy value of ± 0.5 feet (ft). Hence any change in sediment elevation, for interpolated values, that was less than or equal to 0.5 feet and was greater than -0.5 feet, was not included in the calculation of the volume of sediment. The other column uses an accuracy value of ± 1.4 feet (ft), a value suggested by the authors of the LTI Review. As with the ± 0.5 feet accuracy value, any change in sediment elevation, for interpolated values, that was within the interval ± 1.4 feet was not included in the calculation of the volume of sediment.

The table shows, for the accuracy value ± 0.5 feet, that there were fairly consistent volume changes for the year-by-year comparisons except for the years 1998 to 1999. (Note both the volume values as well as the ratios. The latter value is created by dividing the volume gain by the volume loss.) In general, there were more instances of sediment volume gain than loss. This is expected as it confirms the COE need to perform navigational dredging in order to remove areas of sediment elevation. Although the use of the ± 1.4 feet accuracy value shows more instances of sediment volume loss, the cumulative change between 1995 and 2000 shows a gain in sediment volume.

The inclusion of dredge areas in the estimation of sediment volume changes shows, as expected, that the volume estimates in Table 4 are much larger than those in Table 3. This finding demonstrates that a significant proportion of the changed in sediment volumes from one year to the next is due to dredging activities conducted by the COE in the Fox River. As in Table 3, there was one more instance of sediment volume gain greater than loss when the accuracy value ± 0.5 feet was used. Using an accuracy value of ± 1.4 feet shows that there was one more instance of sediment volume loss greater than gain. However, for the period 1995 through 2000, there appears to be a net increase in sediment volume, regardless of the accuracy value used.

Surface area estimates
Tables 5 and 6 provide estimates of the percent of the Fox River study area with significant changes in sediment elevation in year-to-year comparisons. In those portions of the Fox River study area not dredged (see Table 3) approximately 12 to 40 percent of the surface area of the Fox River study area undergoes elevation changes greater than 0.5 feet and less than or equal to -0.5 feet on a year-to-year basis. If an accuracy value of ± 1.4 feet is used, these percent surface area values decrease to 2.5 to 14 percent. If dredge areas are included in the estimation of percent surface area with significant changes in sediment elevation, these values increase (see Table 6). For an accuracy value of ± 0.5 feet, the percentage of the study area with elevation changes ranges from 13 to 40. Using an accuracy value of ± 1.4 feet, these values decrease: 3.5 to 15 percent. As expected, both tables show that there is proportionately more areas with increases in sediment elevation than areas with decreases (see years 1995 to 2000 in Tables 5 and 6).

Maximum change and range of values
Tables 7 and 8 give estimates of the maximum positive and negative change in interpolated sediment elevation values, in feet, for each year-to-year comparison. The tables also show the estimated percentage of values falling within 5 ranges: -0.5 to 0.5 feet, -1.5 to -0.5 feet, < -1.5 feet, 0.5 to 1.5 feet, and > 1.5 feet. As demonstrated in the above figures, a large proportion of estimated sediment elevation changes are within the range of -0.5 to 0.5 feet. However, 7-10% of all estimated sediment elevation changes are greater than 1.5 feet and less than -1.5 feet (see Table 7, non-dredged areas excluded). This range of percentage values increases to 13-15% when dredged areas are included (see Table 8).

Conclusions

The Lower Fox River sediment is part of a dynamic system that warrants close monitoring and in some areas requires repeated dredging over time. The FIELDS Team's maps and analyses of the COE bathymetric survey data show that both erosional and depositional factors are involved in the Fox River sediment system. The remaining questions relate only to the magnitude of those changes. Although the bathymetric surveys performed by the COE cannot be used quantitatively to determine the absolute extent of sediment movement due to dredging activities, they are an indication of a dynamic system that may warrant more detailed analysis. And, as only the navigational channel was surveyed, one cannot extrapolate to areas of the Fox River outside of the navigational bathymetric survey extent. Such a limitation may require that an investigation and possible monitoring for changes in sediment is prudent.

Although sources of this sediment cannot be definitively determined by a bathymetric survey, likely sources of the sediment are runoff (lateral sources), upstream sources, and saltation of existing river sediment. The important point is that, since sediment is being both eroded and deposited in the Fox River system, reasonable care should be taken to avoid having contaminated sediments move into areas currently below the risk level and to avoid having surface sediments with low concentrations of contamination move to expose underlying sediments with higher concentration contamination. Even if net scour is significantly lower than net deposition the preferential movement of certain sediments could greatly increase the overall surface concentration of PCBs, and increase the cost of remediating contaminated sediments as they spread.

References

Limno-Tech, Inc., (LTI), Review of USEPA FIELDS Analysis of Bed Elevation Changes in the Lower Fox River. January, 2002. Referred to in the document as “LTI Review”.

Appendix

Table 1. Dredge dates.

Table 2. Bathymetric Survey and Dredging Dates.

Table 3. Volume estimates (dredged areas excluded).

Table 4. Volume estimates (dredge and non-dredge areas).

Table 5. Surface area estimates (dredged areas excluded).

Table 6. Surface area estimates (dredge and non-dredge areas).

Table 7. Maximum Change and Range of Values (dredged areas excluded).

Table 8. Maximum Change and Range of Values (dredge and non-dredge areas).

Table 1
Dredge dates

Dredge Year	Dredge Dates
1995	August 22 – November 13
1996	August 20 – November 22
1997	September 15 – December 9
1998	September 1 – December 2
1999	July 2 – August 9
2000	August 22 – December 22

The dredging dates in the Lower Fox River were provided by COE Kewaunee office.

Table 2
Bathymetric Survey and Dredging Dates

Survey Transects	Survey dates	Pre- or Post-dredge
0+00 TO 23+00	22JUN95	
24+00 TO 85+00	27JUN95	
86+00 TO 96+00	28JUN95	
97+00 TO 122+00	29JUN95	
123+00 TO 176+00	05JUL95	
177+00 TO 190+00	12JUL95	
0+00 TO 20+00	25JUN96	
21+00 TO 55+00	26JUN96	
56+00 TO 82+00	27JUN96	
83+00 TO 145+00	01JUL96	
146+00 TO 187+84	02JUL96	
176+85 TO 187+84	11SEP96	AFTER DREDGE
0+00 TO 10+00	14NOV96	AFTER DREDGE
19+00 TO 33+00	26NOV96	AFTER DREDGE
0+00 TO 69+00	09JUL97	
70+00 TO 114+00	14JUL97	
115+00 TO 140+00	15JUL97	
140+37 TO 209+00	22JUL97	
142+00 TO 172+00	11DEC97	AFTER DREDGE
0+00	01JUL98	
5+00 TO 45+00	01JUL98	
46+00 TO 109+00	08JUL98	
110+00 TO 162+00	13JUL98	
163+00 TO 176+58	14JUL98	
187+84 TO 215+00	14JUL98	
1+00 TO 4+00	21JUL98	
177+85 TO 188+00	09DEC98	AFTER DREDGE
0+00 TO 35+00	29JUN99	
36+00 TO 105+00	02AUG99	
106+00 TO 155+00	03AUG99	
156+00 TO 210+00	05AUG99	
0+00 TO 65+00	21JUN00	
86+00 TO 142+00	22JUN00	
178+00 TO 190+00	29JUN00	
176+00 TO 177+00	10JUL00	
66+00 TO 85+00	10JUL00	
142+00 TO 176+55	05OCT00	AFTER DREDGE

Table 3
Volume estimates (dredged areas excluded)

Years	Volume Change	± 0.5 ft# (cu. yd)	Ratio (Gain/Loss)*	± 1.4 ft# (cu. yd)	Ratio (Gain/Loss)*
95 - 96	Gain	32,335	1.28	11,698	0.75
	Loss	25,233		15,521	
96 - 97	Gain	34,439	1.24	18,925	1.18
	Loss	27,688		16,087	
97 - 98	Gain	46,408	2.50	25,868	3.45
	Loss	18,591		7,503	
98 - 99	Gain	27,633	0.53	12,316	0.41
	Loss	51,833		30,419	
99 - 00	Gain	39,562	1.15	17,868	0.83
	Loss	34,536		21,590	
95 - 00	Gain	92,035	2.48	62,979	2.64
	Loss	37,075		23,899	

The values in these two columns are cubic yards (cu. yd) of sediment. The difference between these two columns is the accuracy value used. The first column uses an accuracy value of ± 0.5 feet (ft). Hence any change in sediment elevation, for interpolated values, that was less than or equal to 0.5 feet and was greater than -0.5 feet, was not included in the calculation of the volume of sediment. The other column uses an accuracy value of ± 1.4 feet (ft), a value suggested by the authors of the LTI Review. As with the ± 0.5 feet accuracy value, any change in sediment elevation, for interpolated values, that was within the interval ± 1.4 feet was not included in the calculation of the volume of sediment.

* The values in these two columns were created by dividing the volume gain by the volume loss for a particular year-to-year change. These values provide a simple means to compare the year-to-year values to each other.

Table 4
Volume estimates (dredge and non-dredge areas)

Years	Volume Change	± 0.5 ft[#] (cu. yd)	Ratio (Gain/Loss)[*]	± 1.4 ft[#] (cu. yd)	Ratio (Gain/Loss)[*]
95 - 96	Gain	107,870	0.94	59,859	0.69
	Loss	115,205		86,193	
96 - 97	Gain	76,907	0.36	34,011	0.20
	Loss	210,459		173,727	
97 - 98	Gain	170,945	2.88	106,662	3.25
	Loss	59,335		32,838	
98 - 99	Gain	131,862	1.38	71,546	1.23
	Loss	95,449		57,937	
99 - 00	Gain	127,182	1.10	68,134	0.89
	Loss	115,400		76,897	
95 - 00	Gain	198,749	1.49	130,203	1.44
	Loss	133,312		90,278	

[#] The values in these two columns are cubic yards (cu. yd) of sediment. The difference between these two columns is the accuracy value used. The first column uses an accuracy value of ± 0.5 feet (ft). Hence any change in sediment elevation, for interpolated values, that was less than or equal to 0.5 feet and was greater than -0.5 feet, was not included in the calculation of the volume of sediment. The other column uses an accuracy value of ± 1.4 feet (ft), a value suggested by the authors of the LTI Review. As with the ± 0.5 feet accuracy value, any change in sediment elevation, for interpolated values, that was within the interval ± 1.4 feet was not included in the calculation of the volume of sediment.

[*] The values in these two columns were created by dividing the volume gain by the volume loss for a particular year-to-year change. These values provide a simple means to compare the year-to-year values to each other.

Table 5
Surface area estimates (dredged areas excluded)

Years	Elevation Change	± 0.5 ft # (cu. yd)	± 1.4 ft # (cu. yd)
95 - 96	Increase	20.8%	3.6%
	Decrease	14.4%	4.4%
96 - 97	Increase	21.6%	4.8%
	Decrease	14.2%	4.7%
97 - 98	Increase	24.5%	7.4%
	Decrease	12.1%	2.5%
98 - 99	Increase	16.0%	3.6%
	Decrease	24.3%	7.8%
99 - 00	Increase	16.5%	3.9%
	Decrease	39.1%	14.3%
95 - 00	Increase	40.9%	17.8%
	Decrease	17.5%	6.9%

The values in these two columns are cubic yards (cu. yd) of sediment. The difference between these two columns is the accuracy value used. The first column uses an accuracy value of ± 0.5 feet (ft). Hence any change in sediment elevation, for interpolated values, that was less than or equal to 0.5 feet and was greater than -0.5 feet, was not included in the calculation of the volume of sediment. The other column uses an accuracy value of ± 1.4 feet (ft), a value suggested by the authors of the LTI Review. As with the ± 0.5 feet accuracy value, any change in sediment elevation, for interpolated values, that was within the interval ± 1.4 feet was not included in the calculation of the volume of sediment.

Table 6
Surface area estimates (dredge and non-dredge areas)

Years	Elevation Change	± 0.5 ft # (cu. yd)	± 1.4 ft # (cu. yd)
95 - 96	Increase	23.0%	6.9%
	Decrease	18.1%	8.0%
96 - 97	Increase	19.0%	3.5%
	Decrease	27.2%	15.3%
97 - 98	Increase	40.0%	11.1%
	Decrease	13.0%	3.9%
98 - 99	Increase	27.9%	8.6%
	Decrease	18.5%	6.2%
99 - 00	Increase	28.1%	9.0%
	Decrease	20.9%	7.8%
95 - 00	Increase	38.9%	16.0%
	Decrease	24.1%	9.9%

The values in these two columns are cubic yards (cu. yd) of sediment. The difference between these two columns is the accuracy value used. The first column uses an accuracy value of ± 0.5 feet (ft). Hence any change in sediment elevation, for interpolated values, that was less than or equal to 0.5 feet and was greater than -0.5 feet, was not included in the calculation of the volume of sediment. The other column uses an accuracy value of ± 1.4 feet (ft), a value suggested by the authors of the LTI Review. As with the ± 0.5 feet accuracy value, any change in sediment elevation, for interpolated values, that was within the interval ± 1.4 feet was not included in the calculation of the volume of sediment.

Table 7
Maximum Change and Range of Values (dredged areas excluded)

Years	Maximum Change (ft)		% of values in range of -0.5 to 0.5 ft	% of values in Negative Range		% of values in Positive Range	
	Positive	Negative		-1.5 to -0.5 ft	< -1.5 ft	0.5 to 1.5 ft	> 1.5 ft
1995 - 1996	8.5	-9.7	65 %	10 %	4 %	18 %	3 %
1996 - 1997	9.0	-5.9	64 %	10 %	4 %	18 %	4 %
1997 - 1998	9.5	-5.7	63 %	10 %	2 %	18 %	7 %
1998 - 1999	6.8	-10.4	60 %	17 %	7 %	13 %	3 %
1999 - 2000	7.6	-13.9	59 %	12 %	5 %	19 %	5 %
1995 - 2000	8.4	-13.2	42 %	11 %	6 %	25%	16%

Table 8
Maximum Change and Range of Values (dredge and non-dredge areas)

Years	Maximum Change (ft)		% of values in range of -0.5 to 0.5 ft	% of values in Negative Range		% of values in Positive Range	
	Positive	Negative		-1.5 to -0.5 ft	< -1.5 ft	0.5 to 1.5 ft	> 1.5 ft
1995 - 1996	8.5	-12.7	59 %	10 %	8 %	17 %	6 %
1996 - 1997	11.5	-19.8	53 %	13 %	6 %	20 %	8 %
1997 - 1998	13.1	-10.8	52 %	10 %	3 %	25 %	10 %
1998 - 1999	11.2	-12.2	53 %	13 %	6 %	20 %	8 %
1999 - 2000	9.2	-13.8	51 %	14 %	7 %	20 %	8 %
1995 - 2000	8.5	-13.2	38 %	15 %	9 %	23 %	15 %